STAFF REPORT

SUPPLY AND COST OF ALTERNATIVES TO MTBE IN GASOLINE

TECHNICAL APPENDICES

Ethanol Blending Properties
For Task 3 Modeling Work

DECEMBER 1998

CALIFORNIA
ENERGY
COMMISSION

Pete Wilson, ***Governor***

P300-98-013J

M E M O R A N D U M

Date: June 30, 1998

To: Gordon Schremp, California Energy Commission

From: Dave Hirshfeld & Jeff Kolb, MathPro Inc.

Subject: Ethanol Blending Properties for Task 3 Modeling Work

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After we complete the Reference Case runs (incorporating forecasts of long-term refined product demands), we will focus on policy scenarios in which ethanol is the oxygenate in CARB RFG.

The results of this set of cases will be substantially influenced by the blending characteristics assigned to ethanol. The most important of these are ethanol's effects on (1) the RVP and (2) the distillation curve of CARB RFG.

We have developed a new set of blending characteristics for ethanol, based on technical information obtained from the literature and from refiners. This memorandum presents those ethanol blending properties, which we propose to use in analyzing the policy scenarios involving ethanol.

To satisfy the project schedule, we need a fast review of this work by interested parties.

1. EFFECT ON RVP

Exhibit 1 and **Exhibit 3-A** show the effect of ethanol blending on the RVP of finished gasoline.

Exhibit 1 (based on data from the Coordinating Research Council (CRC)) shows that 10 vol% ethanol blending raises the RVP of the base blend by about 1.1 to 1.4 psi. The data indicate that the RVP effect tends to be slightly higher, about 1.3 to 1.4 psi, for base blends with low RVP (5.5 psi, as in a California base blend) than for base blends with RVP above 7 psi.

Exhibit 3-A (based on refiner-supplied information) shows the RVP effect of ethanol blending at various percentages for base blends with RVP of 5.5 to 5.7 psi. These data indicate that most of ethanol's RVP effect occurs at low ethanol concentrations – ethanol blending at a 5 to 6 vol% increases RVP by about 1.3 psi – and that additional ethanol

blending does not further increase (or may reduce) RVP.

Based on these data, we will assume that blending 6 vol% ethanol, which corresponds to a 2.1 wt% oxygen content of finished gasoline, or more, increases RVP by 1.3 psi. To implement this assumption, we will set the RVP of both finished CARB RFG and ethanol at 5.5 psi. This insures that the RVP of the base blend (CARBOB) is 5.5 psi and the RVP of the finished CARB RFG is 6.8 psi (when adjusted for the assumed RVP effect of ethanol blending of 1.3 psi).

2. EFFECT ON THE DISTILLATION CURVE

Exhibit 1 provides data on the distillation curves of six combinations of base blends and 10% ethanol-blended finished gasolines. The data in the upper part of Exhibit 1 show the temperatures at which various percentages of the gasolines are distilled off. For example, for #1 base blend, the T50 is 201° F, i.e., 50% is distilled off at 201° F. The data in the lower part of Exhibit 1 also trace out the distillation curves, but in terms of the percent of gasoline distilled off at specific temperatures. For example, for #1 base blend, the E200 is 49.2%, i.e., at 200° F 49.2% is distilled off. We translate the T values into E values (through linear interpolations) because distillation curves in our refinery model (ARMS) are specified in terms of E values.

Exhibits 2-A, B, and C graph the distillation curves for the #1, #2, and #3 combinations of base blends and 10% ethanol-blended finished gasolines. These three have RVPs closest to CARB RFG, and we have complete distillation curves for them.

These data indicate that ethanol blending:

- affects primarily the front end of the distillation curve, i.e., T50 and lower T values
- has its most substantial effect at T40 (and probably lower T values for heavy base blends) – the T40 reduction averages more than 30° F; and
- may have an effect at T50 that is weakly and inversely related to the T50 of the base blend, i.e., the T50 of the finished gasoline changes least for base blends with higher T50s. (However, the data for T30 and T40 are not consistent with an inverse relationship.)

The #4 combination in Exhibit 1 shows a T50 reduction of 33° F . However, this base blend and finished gasoline have RVP significantly higher than those of CARB base blends and CARB RFG. Comparison of weighted average distillation curves for 8.7 RVP gasohol and conventional gasoline (taken from gasoline surveys) indicates T50 reduction of 13° F for

premium and 48° F for regular. This comparison, however, is not between matched sets of base blend and gasohol; instead, it is between gasohols and finished conventional gasolines. Additionally, the RVP of the gasohol and conventional gasoline is higher than CARB RFG.

Exhibits 3-B, C, and D show (refiner-supplied) data on the changes in T10, T50, and T90 of base blends in response to blending increasing percentages of ethanol. The exhibits include data points for both regular and premium grades. (The original data do not indicate that changes in T10, T50, and T90 depend on the gasoline grade). We have removed anomalous observations from the data set.

These data indicate that the:

- **T10** declines quickly with ethanol blending, up to about 5 vol% ethanol, but blending ethanol in excess of about 5% has no further effect on T10, i.e., the T10 reduction reaches a maximum of about 16° F at 5% to 6% ethanol;

- **T50** appears to decline (somewhat non-linearly) with increasing ethanol blending (and the magnitude of the effect is *not* systematically related to the T50 of the base blend); and

- **T90** also appears to decline with increasing ethanol blending (but less than T10 and T50).

Using the data in Exhibit 1 and Exhibit 3, we developed relationships between ethanol concentration and changes in RVP, T10, T50, and T90. These relationships are shown as the solid lines in Exhibit 3.

3. ETHANOL PROPERTIES FOR ARMS

Exhibit 4 shows our estimates of the effects on gasoline properties of ethanol blending to 6%, 7.7%, and 10% (corresponding to oxygen contents of 2.1 wt%, 2.7 wt%, and 3.5 wt%), along with the corresponding properties for ethanol that will be inserted in the ARMS database. We developed these estimates as follows:

1. We began with the "delta properties" estimated for T10, T50, T90, and RVP at 6%, 7.7% and 10% ethanol blending. (The "delta properties" are consistent with the solid lines in Exhibit 3.)

2. We assumed that for each level of ethanol blending the finished gasoline would be the same and would have properties (T10, T50, T90, and other Predictive Model properties) consistent with those of CARB RFG in the Calibration Case. Although it is unlikely that finished gasolines would be the same for different levels of ethanol blending, this

assumption provides a standard starting point for this analysis and allows us to calculate how base gasoline (CARBOB) properties would change as the level of ethanol blending changes.

3. We applied the "delta properties" to the T10, T50, T90, and RVP of the finished gasoline to calculate those properties for the implied CARBOB at each level of ethanol blending.

4. We developed distillation curves for the CARBOBs and finished gasoline in terms of E values that: (1) are consistent with their T10, T50, and T90 values at each level of ethanol blending; (2) incorporate the large effect of ethanol blending on the distillation curve in the T30 to T40 range; and (3) yield internally consistent E values for "delta properties" and ethanol properties. (The E-values for ethanol are a function of the E value of the starting CARBOB and the delta E value, as indicated in the formula provided in Exhibit 4.) The distillation curves of the CARBOBs and finished gasolines, in terms T values and E values are shown in **Exhibits 5-A, 5-B, and 5-C**.

5. We calculated the oxygen, aromatics, benzene, olefins, and sulfur contents and octane of the CARBOB for each ethanol blending level.

6. For comparison purposes, we calculated the properties of a CARBOB for MTBE blending (at 2.1 wt% oxygen) consistent with the blending values already incorporated in ARMS for MTBE and the results of the Calibration Case. (The distillation curves are shown in **Exhibit 5-D**.)

4. IMPLICATIONS FOR ETHANOL SCENARIOS

The calculations and estimates presented here have several implications for modeling of the ethanol policy scenarios.

- Ethanol CARBOBs must have an RVP of 5.5 psi, significantly lower than the RVP of MTBE CARBOB.

- Ethanol CARBOB for 6% and 7.7% ethanol blending must have higher E200s than MTBE CARBOB to make similar finished gasoline, i.e., they must be lighter.

  Some interested parties have expressed the view that ethanol has a larger impact than MTBE on the T50 (and hence on the E200) of finished gasoline. Our analysis indicates that MTBE has the larger effect – at least for CARB RFG.

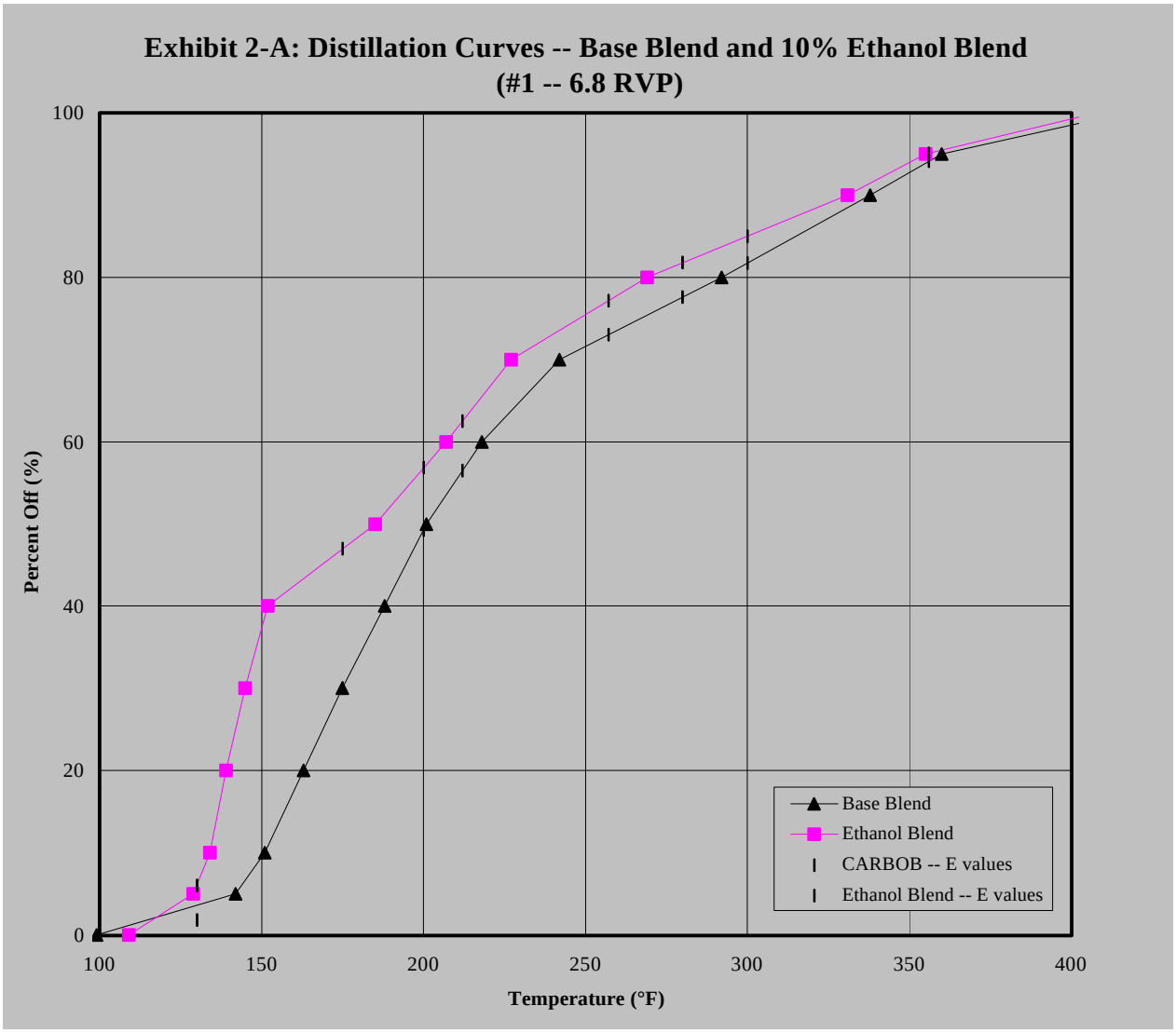
- All ethanol CARBOBs must have higher E300 than MTBE CARBOB to make similar finished gasoline.

- The aromatics and olefins levels of ethanol CARBOBs at 6% and 7.7% ethanol blending must be somewhat lower and the octane higher than MTBE CARBOB to make similar finished gasoline.

Exhibit 1: Distillation Curves for Base Blends and 10% Ethanol Blends -- CRC Publication

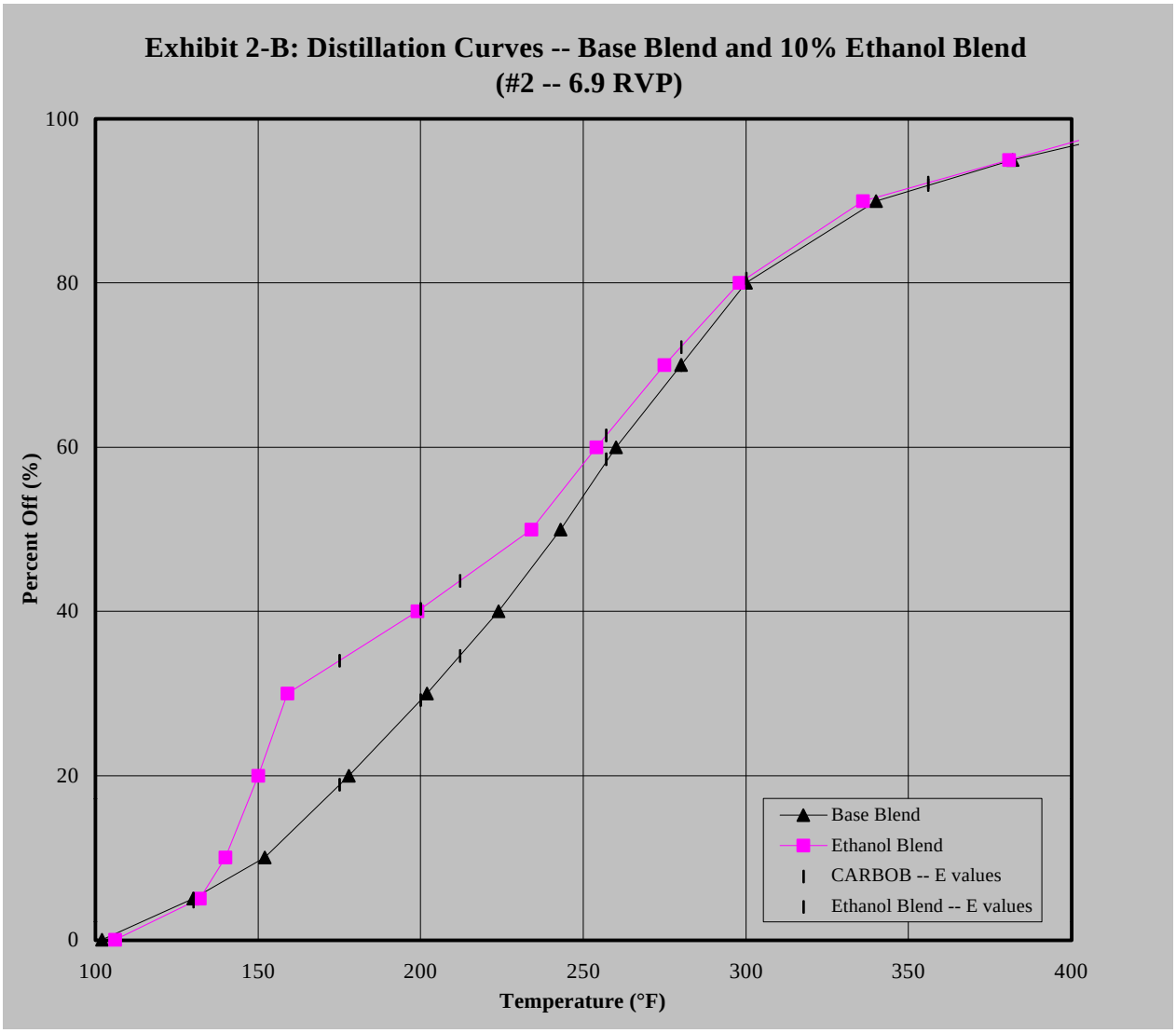
	Base Blend and Corresponding Ethanol Blend																	
	#1			#2			#3			#4			#5			#6		
Distillation/ Property	Base Blend	Ethanol Blend	Delta	Base Blend	Ethanol Blend	Delta	Base Blend	Ethanol Blend	Delta	Base Blend	Ethanol Blend	Delta	Base Blend	Ethanol Blend	Delta	Base Blend	Ethanol Blend	Delta
Temperature (°F) -->																		
IBP	99	109	10	102	106	4	83	95	12	91	83	-8	90	89	-1			
T5	142	129	-13	130	132	2	116	118	2	112	105	-7	108	106	-2			
T10	151	134	-17	152	140	-12	132	126	-6	118	116	-2	124	120	-4	142	133	-9
T20	163	139	-24	178	150	-28	153	137	-16	136	128	-8	158	139	-19			
T30	175	145	-30	202	159	-43	176	147	-29	158	140	-18	198	154	-44			
T40	188	152	-36	224	199	-25	200	159	-41	182	149	-33	228	177	-51			
T50	201	185	-16	243	234	-9	222	208	-14	203	170	-33	248	234	-14	242	234	-8
T60	218	207	-11	260	254	-6	238	233	-5	226	215	-11	267	257	-10			
T70	242	227	-15	280	275	-5	258	253	-5	248	239	-9	286	279	-7			
T80	292	269	-23	300	298	-2	288	283	-5	284	274	-10	305	300	-5			
T90	338	331	-7	340	336	-4	335	332	-3	338	332	-6	332	328	-4	355	351	-4
T95	360	355	-5	382	381	-1	363	366	3	368	364	-4	364	359	-5			
FBP	417	408	-9	436	426	-10	423	409	-14	419	416	-3	424	415	-9			
Percent Off (%) -->																		
E100	0.0	0.0	0.0	0.0	0.0	0.0	2.6	1.1	-1.5	2.1	3.9	1.7	2.8	3.2	0.5			
E130	1.8	6.0	4.2	5.0	4.6	-0.4	9.4	13.6	4.3	16.7	21.7	5.0	11.8	15.3	3.5			
E175	30.0	47.0	17.0	18.8	34.0	15.2	29.6	43.3	13.7	37.1	52.4	15.3	24.3	39.6	15.4			
E200	49.2	56.8	7.6	29.2	40.3	11.1	40.0	48.4	8.4	48.6	64.3	15.7	30.7	44.0	13.4			
E212	56.5	62.5	6.0	34.5	43.7	9.2	45.5	51.6	6.1	53.9	59.3	5.4	34.7	40.4	5.8			
E257	73.0	77.1	4.1	58.5	61.4	2.9	69.5	71.3	1.8	72.5	75.1	2.6	54.7	59.5	4.8			
E280	77.6	81.8	4.2	70.0	72.2	2.2	77.3	79.0	1.7	78.9	81.7	2.8	66.8	70.5	3.6			
E300	81.7	85.0	3.3	80.0	80.5	0.5	82.6	83.5	0.9	83.0	84.5	1.5	77.4	80.0	2.6			
E356	94.1	95.1	1.0	91.9	92.2	0.3	93.8	93.5	-0.2	93.0	93.8	0.8	93.8	94.5	0.8			
RVP (psi)	5.4	6.8	1.4	5.6	6.9	1.3	7.6	8.8	1.2	10.2	11.3	1.1	10.1	11.3	1.2	7.4	8.6	1.2
Ethanol (Vol %)	0	10		0	10		0	10		0			0			0	9.5	
Fuel Number	B	12		D	14		E	15		A	11		C	13		1	6	

Source: Combinations #1 - #5: CRC -- 578, March 1992; Combination #6+C6: CRC -- 585, August, 1993.



	°F				% Off		
% Off	Base Blend	Ethanol Blend	Delta	°F	Base Blend	Ethanol Blend	Delta
0	99	109	10	100	0.0	0.0	0.0
5	142	129	-13	130	1.8	6.0	4.2
10	151	134	-17	175	30.0	47.0	17.0
20	163	139	-24	200	49.2	56.8	7.6
30	175	145	-30	212	56.5	62.5	6.0
40	188	152	-36	257	73.0	77.1	4.1
50	201	185	-16	280	77.6	81.8	4.2
60	218	207	-11	300	81.7	85.0	3.3
70	242	227	-15	356	94.1	95.1	1.0
80	292	269	-23				
90	338	331	-7				
95	360	355	-5				
100	417	408	-9				
RVP (psi)	5.4	6.8	1.4				
Ethanol (Vol %)	0	10					

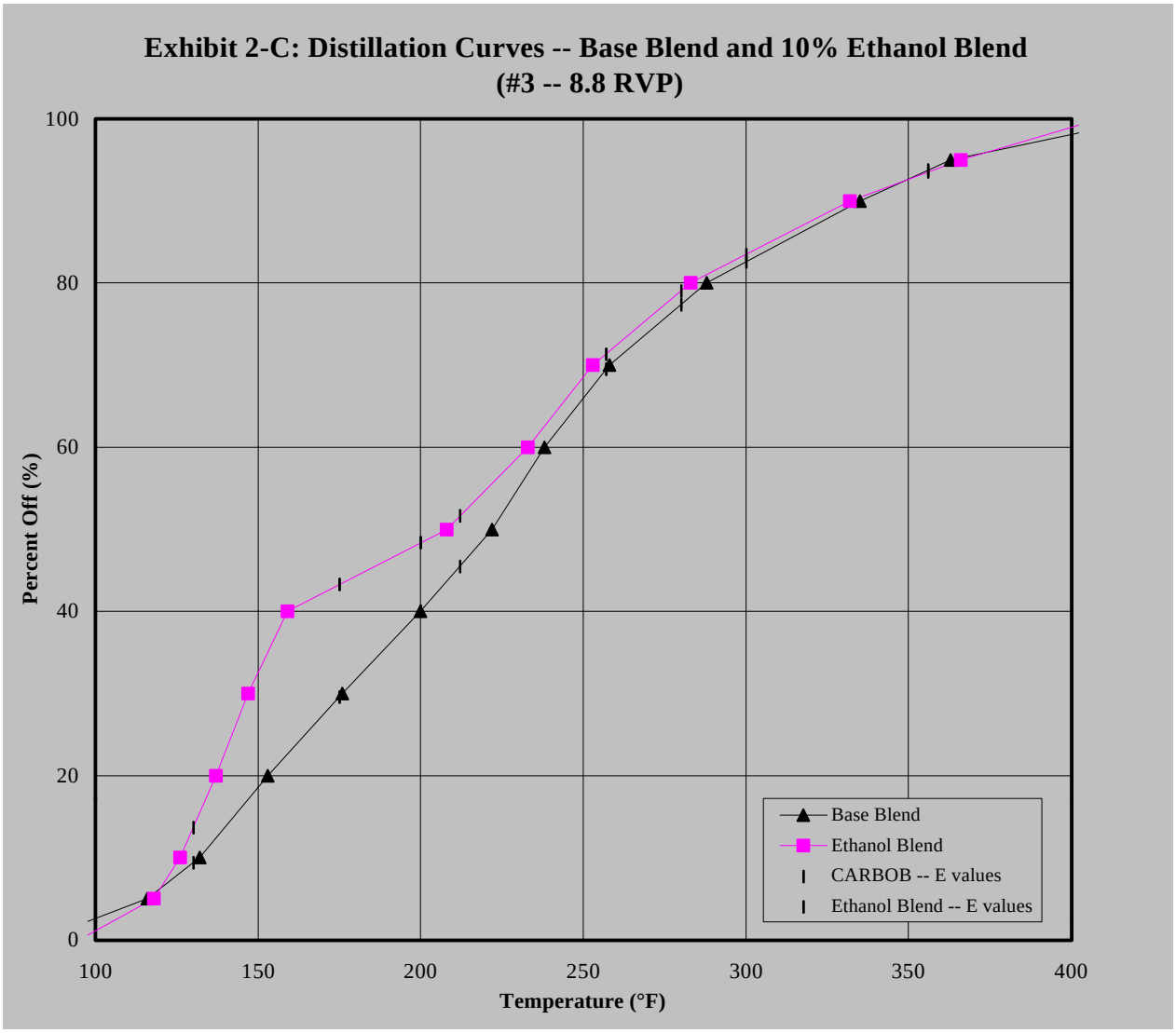
Source: CRC -- 578, March 1992.



	°F				% Off		
% Off	Base Blend	Ethanol Blend	Delta	°F	Base Blend	Ethanol Blend	Delta
0	102	106	4	100	0.0	0.0	0.0
5	130	132	2	130	5.0	4.6	-0.4
10	152	140	-12	175	18.8	34.0	15.2
20	178	150	-28	200	29.2	40.3	11.1
30	202	159	-43	212	34.5	43.7	9.2
40	224	199	-25	257	58.5	61.4	2.9
50	243	234	-9	280	70.0	72.2	2.2
60	260	254	-6	300	80.0	80.5	0.5
70	280	275	-5	356	91.9	92.2	0.3
80	300	298	-2				
90	340	336	-4				
95	382	381	-1				
100	436	426	-10				
RVP (psi)	5.6	6.9	1.3				
Ethanol (Vol %)	0	10					

Source: CRC -- 578, March 1992.

Exhibit 2-C: Distillation Curves -- Base Blend and 10% Ethanol Blend (#3 -- 8.8 RVP)



	°F				% Off		
% Off	Base Blend	Ethanol Blend	Delta	°F	Base Blend	Ethanol Blend	Delta
0	83	95	12	100	2.6	1.1	-1.5
5	116	118	2	130	9.4	13.6	4.3
10	132	126	-6	175	29.6	43.3	13.7
20	153	137	-16	200	40.0	48.4	8.4
30	176	147	-29	212	45.5	51.6	6.1
40	200	159	-41	257	69.5	71.3	1.8
50	222	208	-14	280	77.3	79.0	1.7
60	238	233	-5	300	82.6	83.5	0.9
70	258	253	-5	356	93.8	93.5	-0.2
80	288	283	-5				
90	335	332	-3				
95	363	366	3				
100	423	409	-14				
RVP (psi)	7.6	8.8	1.2				
Ethanol (Vol %)	0	10					

Source: CRC -- 578, March 1992.

Exhibit 3-A: RVP Response of Ethanol Blending

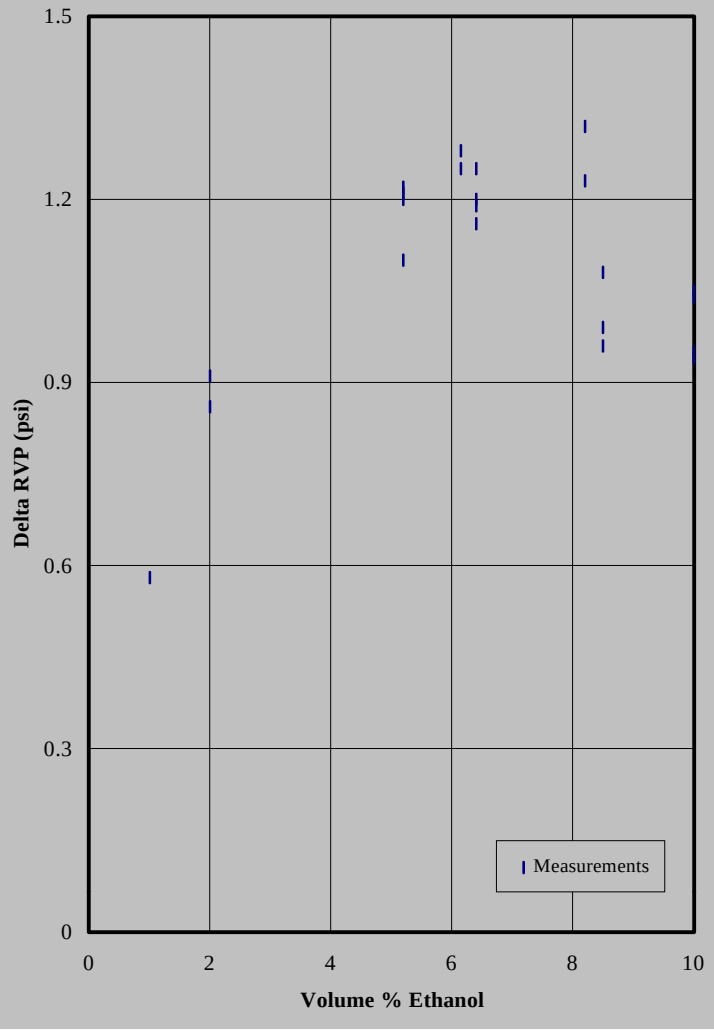


Exhibit 3-B: T10 Response of Ethanol Blending

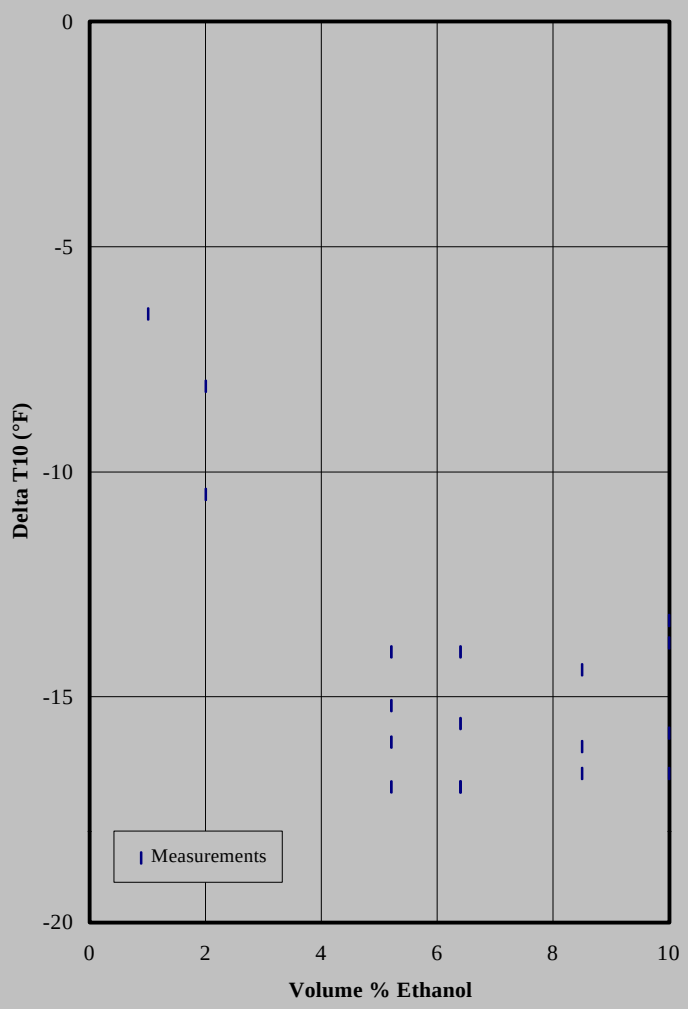


Exhibit 3-C: T50 Response of Ethanol Blending

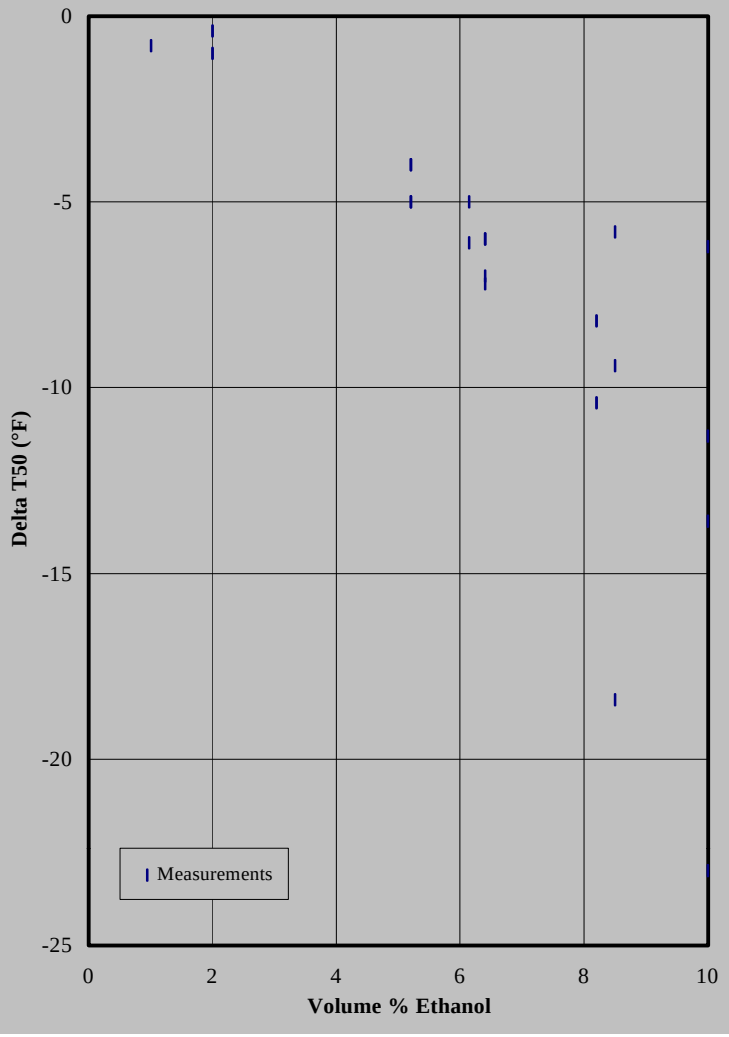


Exhibit 3-D: T90 Response of Ethanol Blending

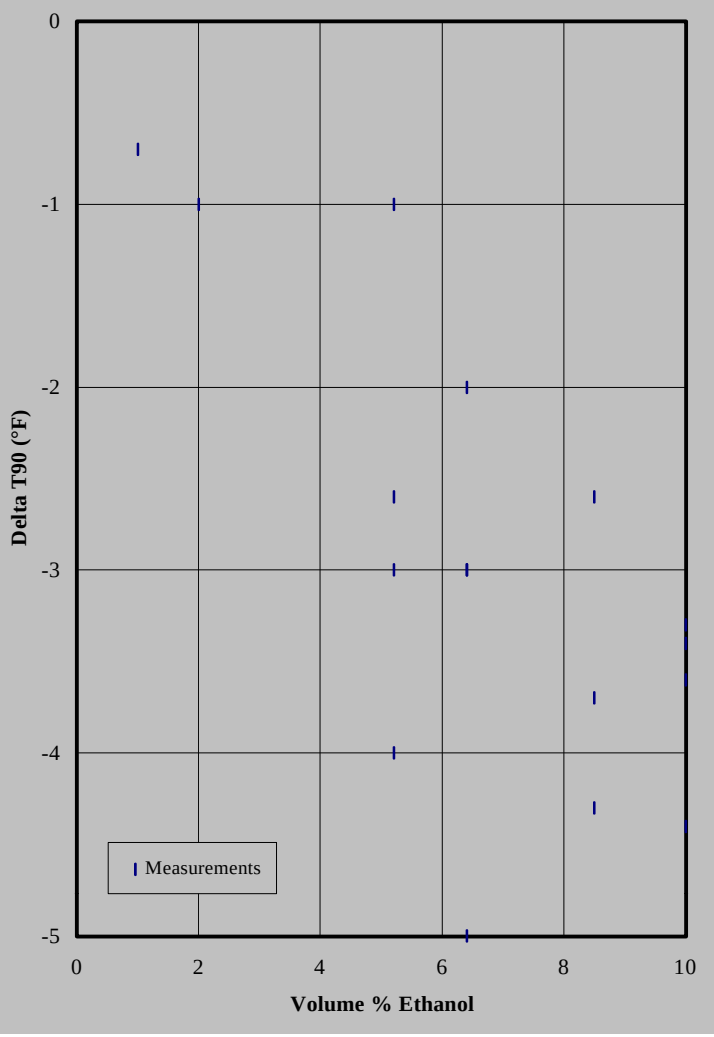
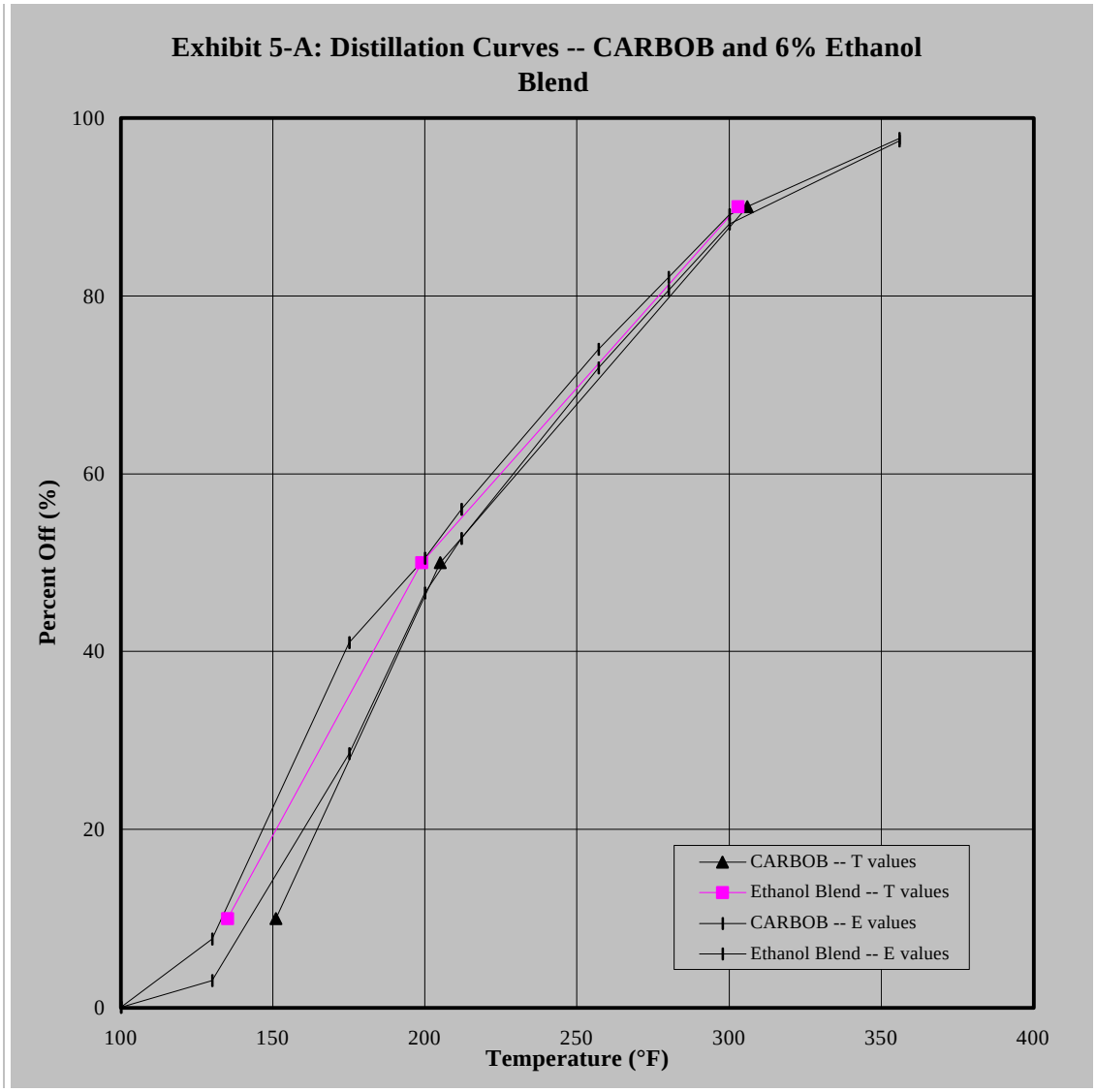


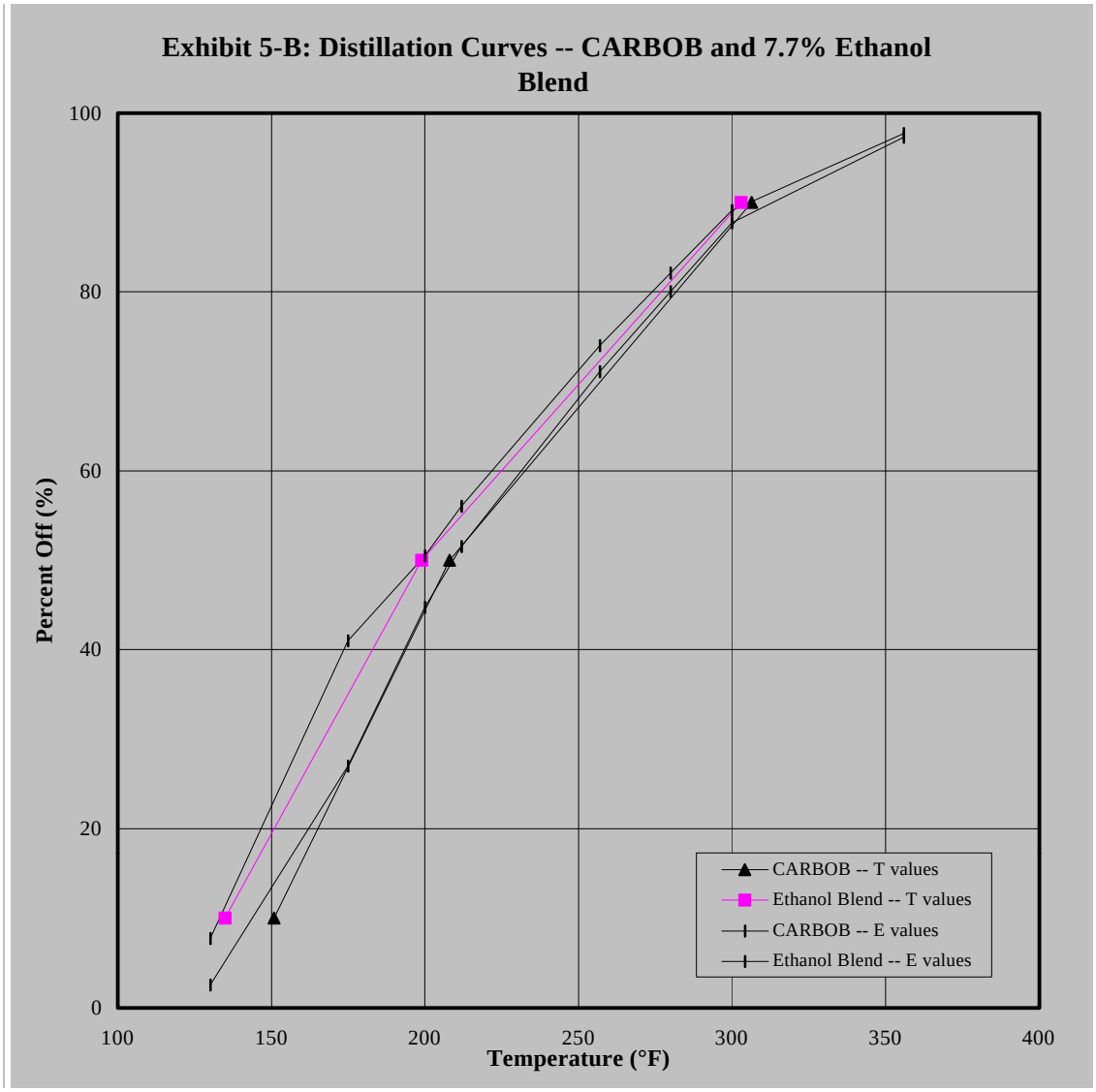
Exhibit 4: Estimated Effect on Gasoline Properties of Ethanol Blending and MTBE Blending

Volume % & Blend	T Values (°F)			Estimated E Values (% Off)									RVP (psi)	Oxy. (wt%)	Arom. (vol%)	Benz. (vol%)	Olef. (vol%)	Sulf. (ppm)	Octane ((R+M)/2)
	T10	T50	T90	E100	E130	E175	E200	E212	E257	E280	E300	E356							
6% Ethanol																			
CARBOB	151	205	306	0	3.0	28.5	46.6	52.7	71.9	80.6	88.1	97.4	5.5	0.0	24.4	0.59	4.6	20.0	87.1
Finished	135	199	303	0	7.7	41.0	50.5	56.0	74.0	82.1	89.1	97.7	6.8	2.1	22.9	0.55	4.3	18.8	88.8
Delta Property	-16.0	-6.0	-3.0	0	4.7	12.5	3.9	3.3	2.1	1.5	1.0	0.3	1.3	-	-	-	-	-	-
Ethanol Property*				0	81.3	236.8	111.6	107.7	106.9	105.6	104.8	102.4	5.5	34.8	0.0	0.0	0.0	0.0	115.0
7.7% Ethanol																			
CARBOB	151	208	307	0	2.5	27.0	44.7	51.5	71.1	80.0	87.7	97.3	5.5	0.0	24.8	0.60	4.7	20.4	86.6
Finished	135	199	303	0	7.7	41.0	50.5	56.0	74.0	82.1	89.1	97.7	6.8	2.7	22.9	0.55	4.3	18.8	88.8
Delta Property	-16.0	-9.0	-3.5	0	5.2	14.0	5.8	4.5	2.9	2.1	1.4	0.4	1.3	-	-	-	-	-	-
Ethanol Property*				0	70.0	208.8	120.0	109.9	108.8	107.3	105.9	102.5	5.5	34.8	0.0	0.0	0.0	0.0	115.0
10% Ethanol																			
CARBOB	151	213	307	0	2.0	25.5	41.5	49.3	70.1	79.5	87.4	97.1	5.5	0.0	25.4	0.61	4.8	20.9	85.8
Finished	135	199	303	0	7.7	41.0	50.5	56.0	74.0	82.1	89.1	97.7	6.8	3.5	22.9	0.55	4.3	18.8	88.8
Delta Property	-16.0	-14.0	-4.0	0	5.7	15.5	9.0	6.7	3.9	2.6	1.7	0.6	1.3	-	-	-	-	-	-
Ethanol Property*				0	59.0	180.5	131.5	116.3	109.1	105.5	104.4	103.1	5.5	34.8	0.0	0.0	0.0	0.0	115.0
11.6% MTBE																			
CARBOB	149	215	309	0.9	5.8	25.8	42.4	48.3	68.9	78.2	86.2	96.0	6.6	0.0	25.9	0.62	4.8	20.0	86.0
Finished	135	199	303	1.5	7.7	35.2	50.5	56.0	74.0	82.1	89.1	97.7	6.8	2.1	22.9	0.55	4.3	18.8	88.8
Delta Property	-14.0	-16.0	-6.0	0.6	1.9	9.4	8.1	7.7	5.1	3.9	2.9	1.7	-	-	-	-	-	-	-
MTBE Property				6.0	22.0	107.0	112.0	115.0	113.0	112.0	111.0	111.0	8.0	18.2	0.0	0.0	0.2	10.0	110.0

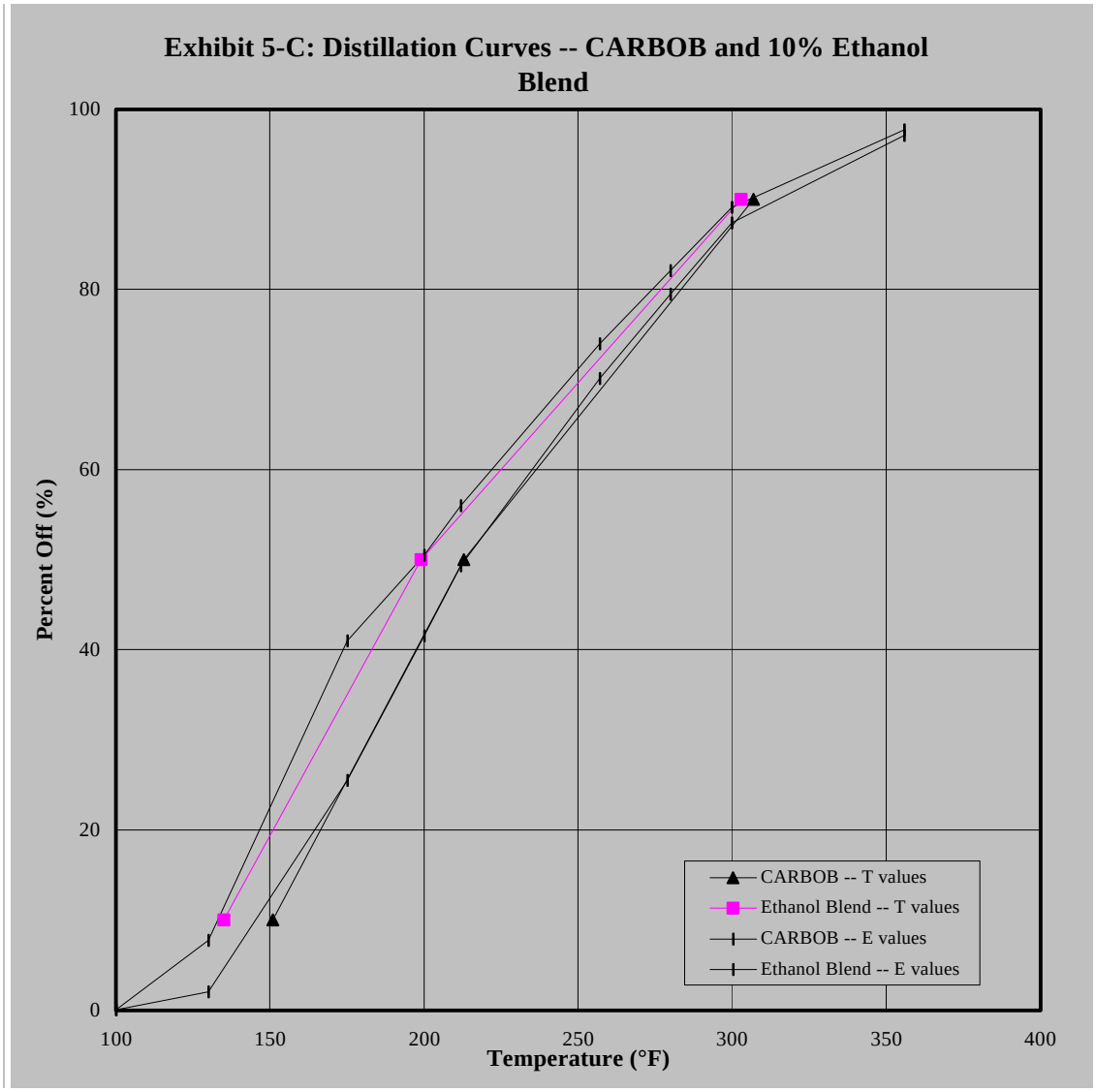
* The E-value for ethanol is given by the formula: E-TEMPethanol = E-TEMPcarbob + (Delta E-TEMP)/ (% Ethanol).



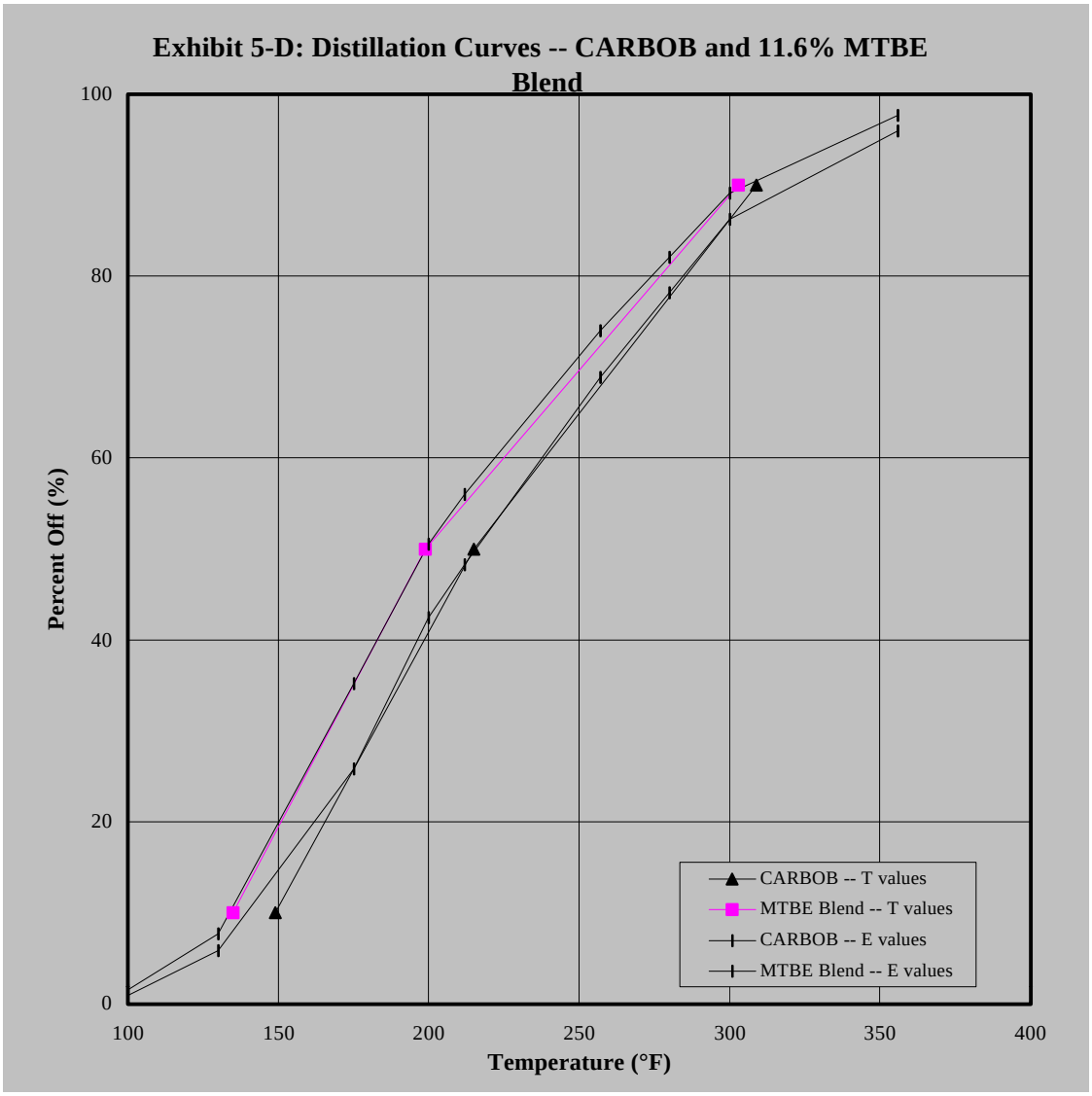
Blend	Percent Off by Temperature								
	100°	130°	175°	200°	212°	257°	280°	300°	356°
CARBOB	0.0	3.0	28.5	46.6	52.7	71.9	80.6	88.1	97.4
Finished	0.0	7.7	41.0	50.5	56.0	74.0	82.1	89.1	97.7
Delta	0.0	4.7	12.5	3.9	3.3	2.1	1.5	1.0	0.3
Ethanol	0.0	81.3	236.8	111.6	107.7	106.9	105.6	104.8	102.4



Blend	Percent Off by Temperature								
	100°	130°	175°	200°	212°	257°	280°	300°	356°
CARBOB	0.0	2.5	27.0	44.7	51.5	71.1	80.0	87.7	97.3
Finished	0.0	7.7	41.0	50.5	56.0	74.0	82.1	89.1	97.7
Delta	0.0	5.2	14.0	5.8	4.5	2.9	2.1	1.4	0.4
Ethanol	0.0	70.0	208.8	120.0	109.9	108.8	107.3	105.9	102.5



Blend	Percent Off by Temperature								
	100°	130°	175°	200°	212°	257°	280°	300°	356°
CARBOB	0.0	2.0	25.5	41.5	49.3	70.1	79.5	87.4	97.1
Finished	0.0	7.7	41.0	50.5	56.0	74.0	82.1	89.1	97.7
Delta	0.0	5.7	15.5	9.0	6.7	3.9	2.6	1.7	0.6
Ethanol	0.0	59.0	180.5	131.5	116.3	109.1	105.5	104.4	103.1



Blend	Percent Off by Temperature								
	100°	130°	175°	200°	212°	257°	280°	300°	356°
CARBOB	0.9	5.8	25.8	42.4	48.3	68.9	78.2	86.2	96.0
Finished	1.5	7.7	35.2	50.5	56.0	74.0	82.1	89.1	97.7
Delta	0.6	1.9	9.4	8.1	7.7	5.1	3.9	2.9	1.7
Ethanol	6.0	22.0	107.0	112.0	115.0	113.0	112.0	111.0	111.0